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Research Note

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ESTIMATING PINYON AND JUNIPER FUEL AND BIOMASS FROM AERIAL PHOTOGRAPHS

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ABSTRACT

Regression equations were developed for estimating mass of various fuel components per unit crown area of singleleaf pinyon (Pinus monophylla) *and Utah juniper* (Juniperus osteosperma). *Techniques are described for using these equations for estimating fuel loading, fuelwood volumes, and potential slash production from aerial photographs.*

KEYWORDS: pinyon, juniper, forest fuel, sampling methods, tree biomass.

The singleleaf pinyon-Utah juniper woodland type occupies about 7 million hectares (17 million acres) in the Great Basin. Little information is presently available on the fuel-loading and biomass characteristics of the type. Information on fuel loading (weight per unit area) is needed for predicting fire behavior (Albini 1976). Information is also needed on how much wood is available for fuelwood and other uses and how much slash would be produced by harvesting operations.

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Accurate determination of biomass and fuel loading requires on-the-ground measurements, but approximations can be made from aerial photographs. Techniques for estimating loading of various fuel size classes from aerial photographs are presented in this Research Note. These techniques are based on regression equations relating mass per unit crown area to maximum crown diameter. Because of the shrubby form of pinyon and juniper, crown area and crown diameter are the only tree dimensions that can be estimated with confidence on aerial photographs.

PAST WORK

Other than the preliminary work by Moessner (1962), there are no publications on the use of aerial photographs in the pinyon-juniper type; however, as a part of Project Flambeau, Storey (1969) weighed 26 pinyon trees and 16 juniper trees near Lee Vining, California. He found that maximum crown diameter was the best single parameter for estimating both aboveground and root biomass of Utah juniper, and for estimating root biomass of singleleaf pinyon. Stem diameter (1 foot [30 cm] above the ground) was slightly better than maximum crown diameter for estimating aboveground biomass of pinyon. His results show that crown measurements alone may be used to estimate biomass.

METHODS

The regression equations were derived from data obtained by felling, sectioning, and weighing 72 singleleaf pinyon and 33 Utah juniper on selected sites across Nevada. Each of these trees was separated into deadwood and three size classes of live material, and then weighed. The three size classes, based on diameter outside bark, were: larger than 3 inches (76 mm), smaller than 1 inch (25 mm), and between 1 and 3 inches. About 10 percent of the less than 1-inch class was subsampled to determine green weights of foliage, twigs smaller than 1/4-inch (6.4 mm), and branches between 1/4- and 1-inch diameter. All sizes of deadwood were weighed together, but the size distribution of deadwood was estimated at the time of weighing. Samples of all size classes from each tree were ovendried at 95° C to determine moisture content.

Depth of litter and duff under the crown of each tree was measured at a point that appeared to represent average depth. Bulk samples of litter (including duff) were taken under four pinyons and three junipers, and ovendried. The apparent densities were 0.091 ± 0.0014 g/cc for pinyon and 0.111 ± 0.005 g/cc for juniper. Under crown fuel loading (kg/m^2) of litter and duff was estimated by multiplying litter and duff depth (cm) by 0.9 kg/m^2/cm for pinyon and 1.1 kg/m^2/cm for juniper. In both species, virtually all litter accumulation occurs under the crowns.

Ovendry mass of the following fuel categories or size fractions (deadwood included) was calculated for regression analysis:

1. Needles or scales (foliage).
2. Twigs smaller than 1/4-inch diameter.
3. Foliage + twigs smaller than 1/4-inch diameter = fine fuels.
4. Twigs and branches larger than 1/4-inch and smaller than 1-inch diameter.
5. Fine fuels + fuels 1/4 to 1 inch = fuels smaller than 1 inch.
6. Stems and branches larger than 1 inch and smaller than 3 inches.
7. Stems and branches smaller than 1 inch + those 1 to 3 inches = stems and branches smaller than 3 inches.
8. Stems and branches larger than 3 inches.
9. Total aboveground biomass: Stems and branches smaller than 3 inches + those larger than 3 inches = total.
10. Litter and duff.

ANALYSIS AND RESULTS

Regression equations were computed for each of the 10 categories for pinyon and juniper. In addition, regression equations were computed for foliage, fine fuels, and litter with pinyon and juniper combined. In all cases, the dependent variable (y) was mass divided by crown area (kg/m^2). Means, standard deviations, and coefficients of variation (CV%) of the dependent variables are tabulated in table 1.

Table 1.--*Equations for estimating mass of fuel components per unit crown area of singleleaf pinyon and Utah juniper. Means ($\bar{y}$), standard deviations (Std. dev.), coefficients of variation (CV%), standard deviations from regression (SDR), and coefficients of variation from regression (CVR%) are listed with each regression equation*

y[1]	Species	$\bar{y}$	Std. dev.	CV%	SDR	CVR%	Regression equation
Foliage/Ca	P	2.15	0.661	30.7	0.639	29.7	$\hat{y} = 0.351x - 0.0272x^2 + 1.21$
	J	2.77	0.787	28.5	0.781	28.2	$\hat{y} = 0.438x - 0.0428x^2 + 1.81$
	P&J	2.35	0.755	32.2	0.736	31.4	$\hat{y} = 0.339x - 0.0289x^2 + 1.51$
<1/4 inch/Ca	P	1.57	0.498	31.8	0.464	29.6	$\hat{y} = 3.088x^{\frac{1}{2}} - 0.645x - 1.96$
	J	0.71	0.275	38.6	--	--	$\hat{y} = \bar{y} = 0.71$
Fine Fuels/Ca	P	3.72	1.040	28.0	0.979	26.3	$\hat{y} = 0.681x - 0.0530x^2 + 1.90$
	J	3.48	0.996	28.6	0.987	24.4	$\hat{y} = 0.579x - 0.0557x^2 + 2.19$
	P&J	3.64	1.028	28.2	0.983	27.0	$\hat{y} = 0.606x - 0.0489x^2 + 2.07$
1/4 to 1 inch/Ca	P	1.50	0.663	44.0	0.562	37.3	$\hat{y} = 4.493x^{\frac{1}{2}} - 0.852x - 4.06$
	J	1.14	0.453	39.7	0.413	36.2	$\hat{y} = 0.412x - 0.0299x^2 - 0.02$
<1 inch[2]/Ca	P	5.21	1.452	27.9	1.265	24.3	$\hat{y} = 4.074x^{\frac{1}{2}} - 0.0591x^2 - 1.94$
	J	4.62	1.339	29.0	1.314	28.4	$\hat{y} = 0.991x - 0.0856x^2 + 2.17$
1 to 3 inches/Ca	P	2.67	1.449	54.3	0.999	37.4	$\hat{y} = 1.358x - 0.0780x^2 - 1.85$
	J	1.84	0.767	41.7	0.602	32.7	$\hat{y} = 5.756x^{\frac{1}{2}} - 1.073x - 5.35$
<3 inches/Ca	P	7.87	2.554	32.5	1.916	24.3	$\hat{y} = 8.305x^{\frac{1}{2}} - 0.1000x^2 - 7.35$
	J	6.46	1.958	30.3	1.831	28.4	$\hat{y} = 1.820x - 0.1422x^2 + 1.57$
>3 inches/Ca	P	6.92	5.939	85.8	4.493	64.9	$\hat{y} = 1.680x - 1.78$
	J	2.87	1.733	60.4	1.312	45.8	$\hat{y} = 0.0520x^2 + 1.53$
Total/Ca	P	14.79	7.756	52.4	5.794	39.2	$\hat{y} = 10.46x^{\frac{1}{2}} - 8.44$
	J	9.33	3.216	34.5	2.803	30.0	$\hat{y} = 3.774x^{\frac{1}{2}} + 1.30$
Litter/Ca	P	5.40	3.628	67.1	2.440	45.2	$\hat{y} = 2.227x - 0.0878x^2 - 3.30$
	J	5.12	3.369	65.8	2.209	43.1	$\hat{y} = 1.315x - 1.06$
	P&J	5.32	3.535	66.5	2.362	44.4	$\hat{y} = 2.087x - 0.0754x^2 - 2.90$

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[1] y = fuel mass/crown area (kg/m^2); Ca = crown area (m^2); x = maximum crown diameter (m); P = pinyon (72 observations); J = juniper (33 observations); P&J = pinyon and juniper combined (105 observations).

[2] One inch = 25 mm.

The following model was used in all regression analysis:

$$\hat{y} = a + bx + cx^{\frac{1}{2}} + dx^{2}$$

in which x is maximum crown diameter.

In the final equations (table 1), only those terms contributing to minimum standard deviation from regression (SDR) have been retained. In every case, at least one term was superfluous. Two terms provided the smallest SDR in most cases. For juniper twigs smaller than 1/4 inch, the mean value (0.71 kg/m^2) provides the best estimate because none of the terms reduced the SDR below the standard deviation.

Coefficient of variation from regression (CVR%) is analogous to coefficient of variation (CV%), being the standard deviation from regression expressed as a percentage of the mean (Draper and Smith 1966, p. 119). The coefficient of variation (CV%) provides an indication of the error to be expected if the mean ($\bar{y}$) is used for estimation and CVR% provides an indication of the error to be expected if the regression equation is used. Comparison of CV% with CVR% shows about how much the accuracy of estimation can be improved by use of regression.

Foliage mass per unit crown area is about the same at all crown sizes (fig. 1) and little is gained by regression; the means are nearly as accurate as the regression equations. The relation between fine fuels per unit crown area and crown diameter is a little more pronounced than that for foliage alone. Juniper tends to have more foliage mass per unit crown area than pinyon, but pinyon has more twig mass, resulting in greater fine fuel mass per unit crown area for pinyon. Except for foliage, pinyon has more mass per unit crown area than juniper in all size classes.

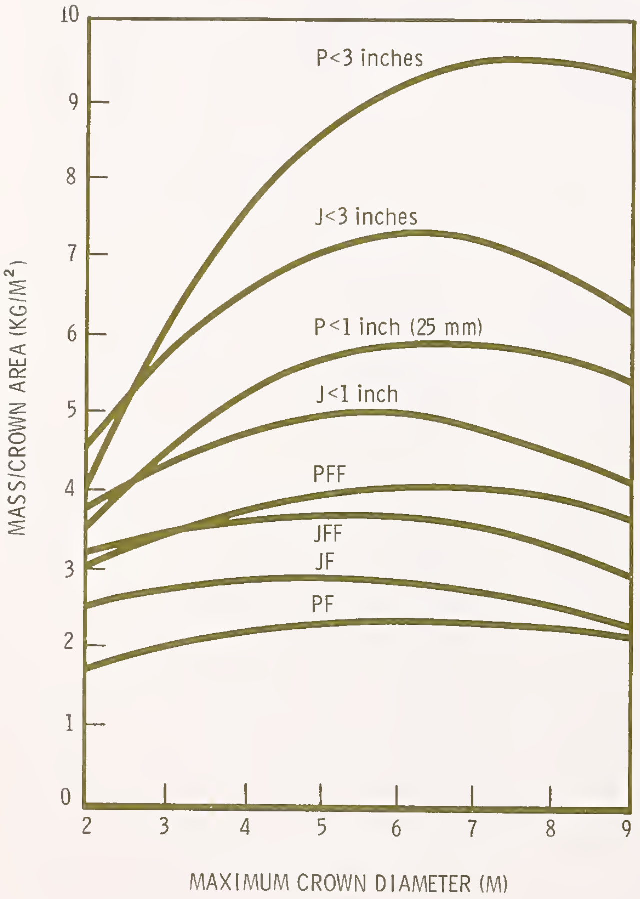

Figure 1.--Mass of foliage (F), foliage and twigs <1/4 inch or fine fuels (FF), all fuels smaller than 1 inch (25 mm) diameter, and all fuels smaller than 3 inches (76 mm) diameter per square meter crown area of singleleaf pinyon and Utah juniper at maximum crown diameters from 2 to 9 meters (from table 3).

As we go to larger size classes, the effect of crown size becomes greater and the maxima occur at larger crown diameters. Mass per unit crown area of stems and branches larger than 3 inches in diameter increases at a constant rate (pinyon) or a slightly increasing rate (juniper) as crown diameter increases (fig. 2).

Litter and duff mass per unit crown area is nearly proportional to crown diameter. Pinyon litter tends to be deeper than juniper litter for a given crown size, but juniper litter tends to be more tightly packed; so the net result is virtually no difference in litter mass per unit crown area between the two species. Although pinyon and juniper produce less litter annually than most other tree species, decomposition rates are low and accumulated litter is a major fuel component.

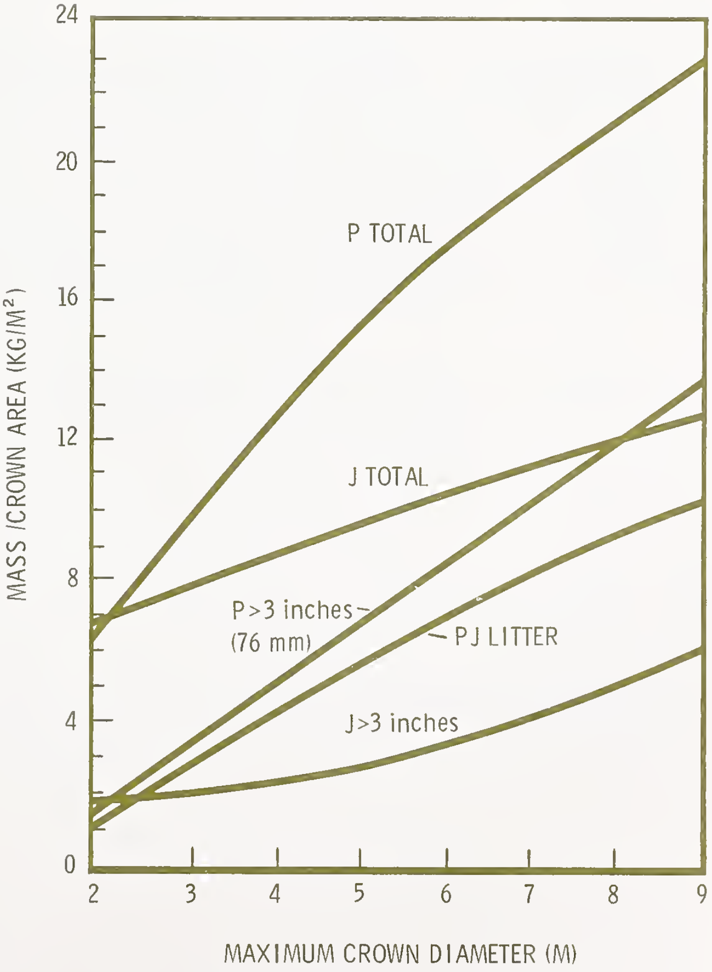

Figure 2.--Total aboveground biomass, mass of stem and branchwood larger than 3 inches (76 mm) diameter and mass of litter and duff per square meter crown area of singleleaf pinyon and Utah juniper at maximum crown diameters from 2 to 9 meters (from table 3). Because pinyon and juniper litter curves are nearly identical, the curve for pinyon and juniper combined is shown.

The amounts of deadwood and moisture in each fuel component are very important in evaluating flammability. Estimates of these are provided in table 2. In all size classes except twigs smaller than 1/4 inch, juniper had a much lower percentage of deadwood than pinyon. Deadwood percent in juniper generally increases with increasing crown size. In pinyon, percent of deadwood larger than 1 inch tends to increase as crown size increases, but percent deadwood smaller than 1 inch is about the same for all crown sizes.

The mean moisture contents of the components (table 2) were calculated from moisture contents at the time the trees were cut. No trends in moisture content throughout the summer were detected, but foliage and twigs probably contain more moisture during the peak growing season in the spring.

Table 2.--*Mean percent deadwood and mean percent moisture (dry weight basis) in the fuel components. Means were weighted by reciprocal of crown area. Mean moisture content of deadwood of both species was 14 percent.*

			Moisture content			
	Deadwood		Live only		Alive and dead	
Component	P[1]	J[1]	P	J	P	J
	Percent					
Foliage	--	--	104	91	104	91
Twigs <1/4 inch	25	25	108	91	85	72
Fine fuels	11	5	106	91	96	87
1/4 - 1 inch	27	16	96	100	74	86
< 1 inch[2]	16	8	103	93	89	87
1 - 3 inches	21	5	79	96	66	92
<3 inches	17	7	95	94	81	88
>3 inches	4	1	79	92	76	91
Total	11	5	87	93	79	89

[1] P = pinyon; J = juniper.
[2] One inch = 25 mm.

ESTIMATION TECHNIQUES

The regression equations and means in table 1 can be used in several different ways to estimate fuel loading and biomass from aerial photographs, depending on what information is desired and on available photo coverage.

If an approximation of average fine fuel loading is needed for a large area, it can be obtained by determining the proportion of canopy cover on the area of interest and multiplying it by the mean for both species (3.64 kg/m^2, table 1). This simple procedure is adequate because fine fuels per unit crown area are about the same for both species at all crown sizes. This procedure might be used also for the 1/4- to 1-inch size class but, for any other component, more elaborate techniques are required.

If an estimate of litter is desired, a sampling procedure for determining crown diameter is needed because of the dependence of litter mass per unit crown area on crown size.

For estimates of size fractions larger than 1 inch, it is necessary to identify species on the photographs or know, from other sources, the relative proportions of pinyon and juniper on the site and their relative size distributions. A photo scale of 1:5000 or larger is needed to distinguish between pinyon and juniper. (Personal communication, Paul Tueller, Professor, Division of Renewable Natural Resources, University of Nevada Reno.)

The following procedure is suggested for sampling on photographs of sufficient resolution to allow reasonably accurate determination of species and crown diameter. The sampling unit is a 10-point grid, with an equivalent spacing of 10 to 20 meters between points, placed on the photograph. For each point on a crown, measure maximum crown diameter to the nearest meter and determine species. For each fuel component of interest, read from table 3 the mass per unit crown area (kg/m^2) at each occupied point. The sum of these values divided by 10 (the number of points in the sampling unit) is the estimated fuel component mass in kilograms per square meter of land area. Since 1 kilogram per square meter equals 10 metric tons per hectare, the sum of the values is estimated fuel loading in metric tons per hectare.

For example, say three pinyons with maximum crown diameters of 3, 4, and 8 meters and two junipers with maximum crown diameters of 2 and 4 meters are tallied on a 10-point sampling unit. The estimate of fine fuels for that sampling unit is 18.0 MT/ha (3.5 + 3.8 + 4.0 + 3.1 + 3.6). The estimate of stems and branches larger than 3 inches in diameter is 24.0 MT/ha (3.3 + 4.9 + 11.7 + 1.7 + 2.4). Estimated litter is 21.5 MT/ha or, if we use the line for pinyon and juniper combined, 21.1 MT/ha.

A survey would consist of many such sampling units. Stratification based on tree density, landform, soil taxa, and other such criteria would probably increase precision.

This procedure can be easily modified to meet particular needs. In addition to providing fuel loading information for fire management, the technique may be used for other purposes, such as obtaining rough estimates of cordwood volumes and the amount of slash that would result from cutting operations.

Table 3.--*Mass of fuel components per unit crown area of singleleaf pinyon and Utah juniper, based on the regression equations in table 1*

Component	Species	Maximum crown diameter (meters)									
		1	2	3	4	5	6	7	8	9	10
		Kg/m^2									
Foliage	P	1.5	1.8	2.0	2.2	2.3	2.3	2.3	2.3	2.2	2.0
	J	2.2	2.5	2.7	2.9	2.9	2.9	2.8	2.6	2.3	1.9
	P&J	1.8	2.1	2.3	2.4	2.5	2.5	2.5	2.4	2.2	2.0
Twigs <1/4 inch	P	0.5	1.1	1.5	1.6	1.7	1.7	1.7	1.6	1.5	1.4
	J	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Fine fuels	P	2.5	3.0	3.5	3.8	4.0	4.1	4.1	4.0	3.7	3.4
	J	2.7	3.1	3.5	3.6	3.7	3.7	3.5	3.3	2.9	2.4
	P&J	2.6	3.1	3.5	3.7	3.9	3.9	3.9	3.8	3.6	3.2
1/4 - 1 inch	P	--	0.6	1.2	1.5	1.7	1.8	1.9	1.8	1.8	1.6
	J	0.4	0.7	0.9	1.1	1.3	1.4	1.4	1.4	1.3	1.1
<1 inch[1]	P	2.1	3.6	4.6	5.3	5.7	5.9	5.9	5.8	5.5	5.0
	J	3.1	3.8	4.4	4.8	5.0	5.0	4.9	4.6	4.2	3.5
1 - 3 inches	P	--	0.6	1.5	2.3	3.0	3.5	3.8	4.0	4.1	3.9
	J	--	0.6	1.4	1.9	2.2	2.3	2.4	2.3	2.3	2.1
<3 inches	P	0.9	4.0	6.1	7.7	8.7	9.4	9.7	9.7	9.5	8.9
	J	3.2	4.6	5.8	6.6	7.1	7.4	7.3	7.0	6.4	5.6
>3 inches	P	--	1.6	3.3	4.9	6.6	8.3	10.0	11.7	13.3	15.0
	J	1.6	1.7	2.0	2.4	2.8	3.4	4.1	4.9	5.7	6.7
Total	P	2.0	6.4	9.7	12.5	14.9	17.2	19.2	21.1	22.9	24.6
	J	5.1	6.6	7.8	8.8	9.7	10.5	11.3	12.0	12.6	13.2
Litter	P	--	0.8	2.6	4.2	5.6	6.9	8.0	8.9	9.6	10.2
	J	0.3	1.6	2.9	4.2	5.5	6.8	8.1	9.5	10.8	12.1
	P&J	--	1.0	2.7	4.2	5.6	6.9	8.0	9.0	9.8	10.4

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[1] One inch = 25 mm.

For cordwood and slash, we would tally only those trees large enough to harvest. The average ratio of stump diameter to crown diameter for pinyon and juniper is 1 to 14. If we assume a minimum stump diameter of 15 cm (6 inches), the minimum crown diameter is 210 cm and we would tally only those trees with crown diameters greater than 2 meters. Continuing with the example given above and taking the larger than 3-inch size class as cordwood, the estimate of cordwood for the sampling unit is 19.9 MT/ha pinyon and 2.4 MT/ha juniper. The smaller juniper did not count. These figures can be converted to cubic foot volume or cords per acre with the following conversion factors:

Pinyon: 1 MT/ha = 31 ft^3/acre = 0.36 cords/acre
Juniper: 1 MT/ha = 38 ft^3/acre = 0.44 cords/acre

The estimated cords per acre on the example sampling unit is 7.2 pinyon and 1.1 juniper.

For the slash estimate, we use the smaller than 3-inch component and obtain 30.1 MT/ha (6.1 + 7.7 + 9.7 + 6.6) for the three pinyons and one juniper tallied on the sampling unit. Since 1 MT/ha = 0.446 tons per acre, this amounts to about 13 tons of slash per acre from cordwood cuttings.

Other applications can be developed for this technique, but it should be remembered that the results are approximate. The CVR% values in table 1 show that estimation errors can be quite high, particularly for the larger size classes. Some form of double sampling, incorporating on-the-ground measurements of stem diameter and height, would be needed to improve estimates of the larger size classes.

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